Perspective on CCS – Cost, Energy & Scale

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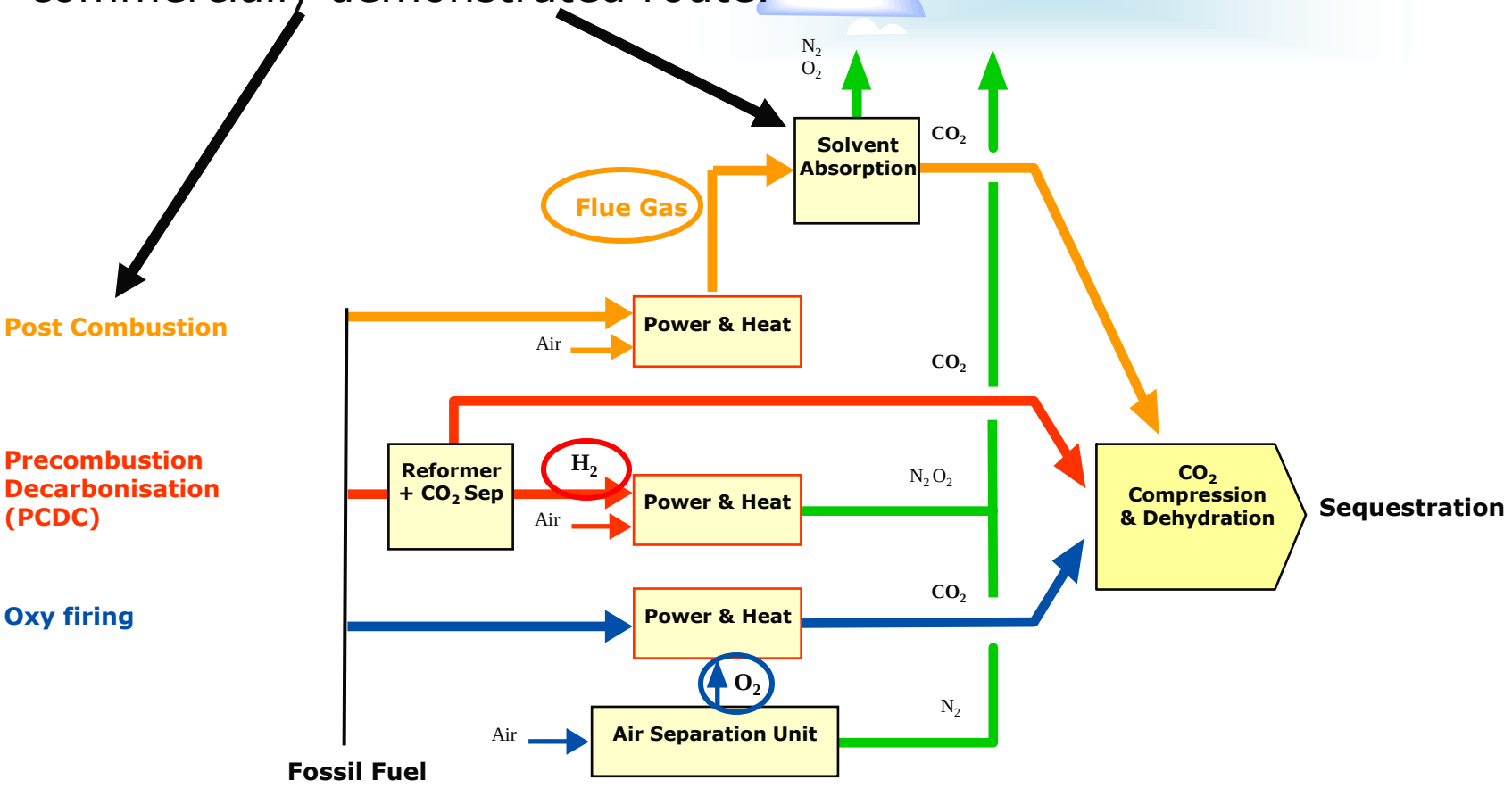
There are three main approaches to CO_2 Capture from combustion operations. (And no silver bullets)

Post combustion capture using solvent scrubbing is the only commercially demonstrated route.



A sense of scale

400 MW (net) NGCC -> 1.4 Mtpa of CO2

500 MW (net) SC PC -> 3.5 Mtpa of CO2

Chevron's Richmond Refinery -> ~4 Mtpa of CO2

How big are the pipelines? [1]

For 3.6 Mtpa about 12 inch ID

For 50 Mtpa about 28 inch ID

How large is a Giga-tonne?

About 320 500-MW PC plants (~50% of current US name plate coal capacity)

Note 1: See "The Cost of CCS in the Perth Region," Allinson et al, SPE 101122-PP

Post-Combustion CO_2 Capture

- Key CO_2 sources are boilers, heaters, and turbines
- Flue gas is hot, low pressure, and dilute in CO_2 (4-10 vol.%)
- Current technology is proven and is based on amine scrubbing using very large equipment
- Large energy requirements for CO_2 recovery
- Other flue gas components (e.g., O_2, NO_X, SO_X degrade amines)

This picture shows the absorber (foreground) and the stripper for removing CO_2 from the flue gases from an equivalent of a 40 MW gas fired power plant.

ECONAMINE^{TM} Unit at Bellingham, MA CO_2 Plant
Courtesy of Val Francuz (Fluor) and Cliff Lowe (Chevron)

A 500 MW SCPC scrubber is 20m in diameter

Issues/Barriers for Capture Technology (US DOE view circa 2004 … and still true)

Post-Combustion Capture (the only industrially proven approach)

- **CO_2 in flue gas is dilute – requiring large gas-handling systems.**
- **Other flue gas components (O_2, SOx, NOx, particulate) adversely affect separation tech's.**

PreCombustion Decarbonization

- **Existing CO_2 removal tech's operate at low T, requiring syngas cooling/ reheat.**
- **Often cheaper to combust syngas before full shift, reducing fraction CO_2 captured.**

Oxy-Fired Combustion

- **Cryogenic air separation is costly.**
- **Pure oxy combustion T too high for existing materials & mediation by CO_2 recycle uses energy.**

Crosscutting Science

- **CO_2 capture tech's have poor selectivity and/or require significant heating/cooling.**
- **Decreased efficiency and resulting increased fuel use is going the wrong direction. AS MUCH AS 1/3 POWER PLANT OUTPUT.**

Bottom Line

CO_2 Capture is COSTLY!

Some rough costs

Post-combustion capture on H2 Plant[1]

- 8330 kmol/hr H2 releases ~1.2 mtpa CO2
- Capital cost of Amine Scrubber ~$500 MM (4Q07)
- CO2 avoided cost $71/tonne (85% capture)

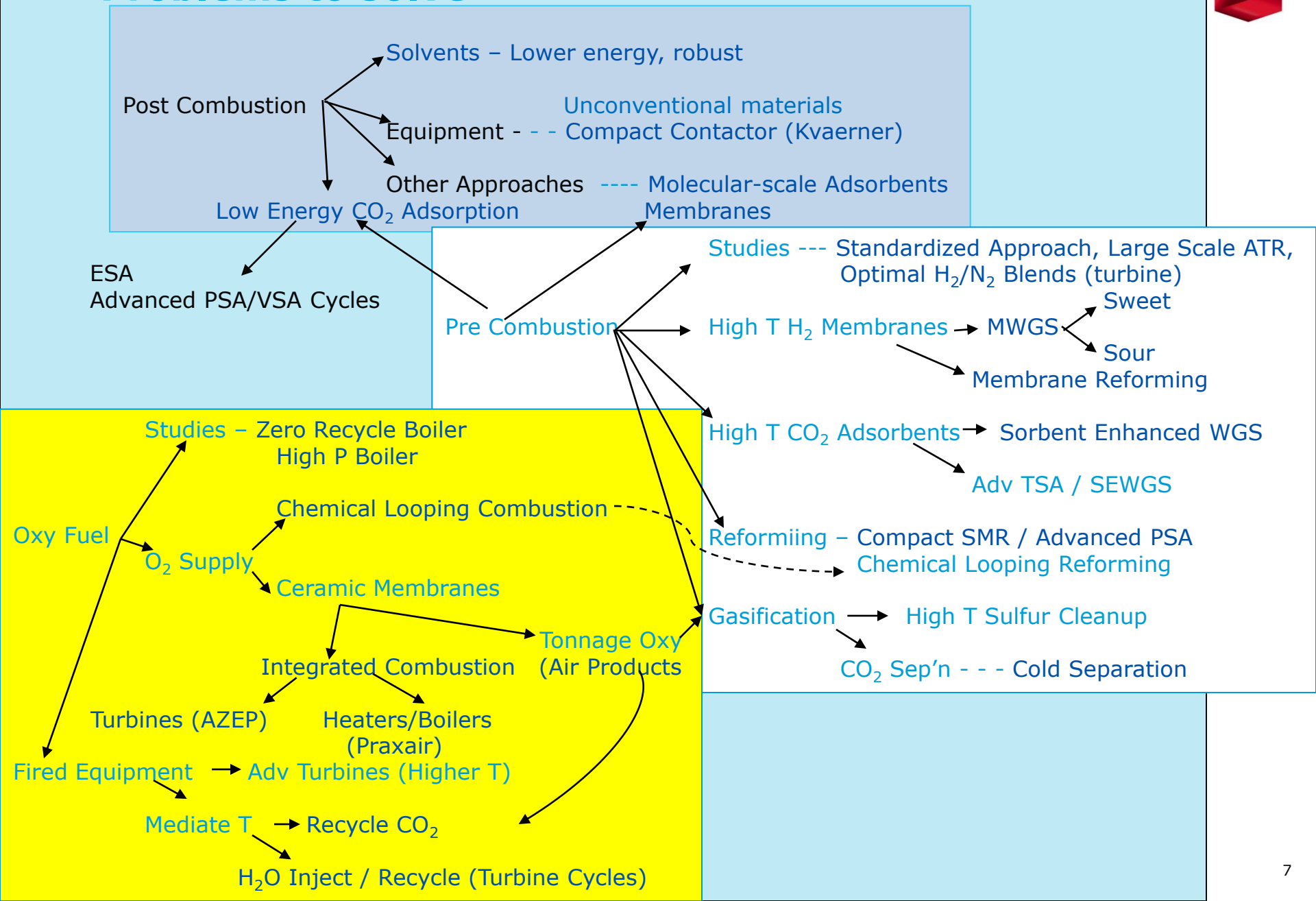
Post-C capture on small NGCC Plant[2]

- 660,000 mtpa CO2 captured (~200 MW)
- Capital cost of amine system ~$350 MM
- CO2 avoided cost $157/tonne (70% capture)

Note 1: "Designing a Climate Friendly H2 Plant,"Lindsay et al, GHGT9

Note 2: Internal study

CO_2 CAPTURE TECHNOLOGY MAP – Yes, there are Problems to solve



Summary

CO_2 Capture is Costly.

- Perhaps 70% of total CCS cost chain.
- Economy of Scale is crucial.
- Promising technologies are emerging, but time is running out.
- There are no silver bullets – economics are very site specific.

CO_2 Capture does not occur in a vacuum.

- Transportation infrastructure - huge. How to pay?
- Secure storage sites.

The oil and gas industry has experience with all of these technologies, but none are demonstrated for widespread deployment.